CHARACTERIZATION OF THE MICROSTRUCTURE AND MECHANICAL PROPERTIES IN SEASONAL LAKE AND RIVER ICE

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ABSTRACT

This ongoing study focuses on the effects of the microstructure and impurities on the mechanical behavior of both seasonal lake and river ice. Ice was collected yearly over a 4-year period (2001-2004) from the same locations, from Lower Baker Pond, Orford, NH and the Connecticut River near Hanover, NH. Mechanical testing coupled with microstructural analysis of the texture of lake and river ice revealed that fracture models and strengths inferred from tests performed on S2 lab ice can be used to provide strength estimates for river ice but their use for lake ice is problematic.

1. INTRODUCION

Characterizing the mechanical behavior of the seasonal ice covers over rivers and fresh-water lakes is an important task in predicting the loads that develop on bridges and other engineering structures during their interaction with the ice sheet. Using laboratory-grown ice to investigate the failure modes of natural ice and to predict its strength is the most common and simplest approach. However, microstructural analysis has revealed that the microstructure and texture of lake ice change both through the thickness of the ice sheet as well as with location in the lake. Consequently the mechanical properties of lake ice vary and its mechanical behavior cannot be reliably predicted using laboratory ice. In this paper we investigate the microstructure of seasonal lake and river ice and relate the finding to its fracture strength in the brittle regime under biaxial in-pane compression.

2. APPROACH

Accretion ice (accretion ice is formed by freezing water, as opposed to ice formed by freezing and compacting wet snow) was collected yearly over a 4-year period from the same locations: for lake ice the locations were near the shore, middle of the lake, and along the main inlet of Lower Baker Pond, Orford, NH, while river ice was extracted from roughly half way between the banks of the Connecticut River near Hanover, NH. The ice was stored in a cold room at -10°C. To analyze the texture of the ice, thin sections (~ 0.5 mm) were made in ~30 mm increments along the thickness. Adjacent approximately 152 mm x 152 mm x 25 mm sections were used to produce corresponding compression test specimens. The specimens were biaxially compressed with a small degree of lateral confinement (~7.5-10.5%) in the brittle regime using a MTS multi-axial testing system. The strain-rate along the main compressive axis was 5×10^{-3} s^{-1}. All tests were performed at $-10^{\circ} \pm 0.2^{\circ}$ C.

3. RESULTS

3.1 Lake Ice

Measurements of the thickness of the seasonal ice cover over the Upper Baker Pond in 2004 at the collection locations showed that the ice was thickest in the middle of the lake and thinnest along the inlet.

Figure 1 shows the microstructure of Upper Baker pond ice, at three depths along the thickness. Microstructural analysis of the lake accretion ice revealed several important trends:

1. Lake ice is primarily S1 ice, with a very tight C-axis alignment, i.e. the C-axes of the grains are oriented within 5°-6° from the vertical (the gray areas including darker shades and black in Fig. 1 are indicative of S1 ice). Clusters of grains with orientations other than S1 (bright colors) are commonly visible in the top layers but these non-S1 orientations decrease rather quickly with increasing depth and do not "survive" below a relatively shallow depth.
2. Near the shore, the top layers of the ice exhibit clusters of smaller non-S1 grains, most likely due to the numerous possible nucleation sites (soil particles, organic matter, etc). In contrast, due to a less perturbed growth process, the ice in the middle of the lake exhibited significantly larger grains (all of S1 orientation) with longer and straighter grain boundaries and notably fewer non-S1 grains in the top part.
3. The ice along an inlet is greatly affected by the flow. In this region, the ice has the smallest thickness and its microstructure exhibits large areas with non-S1 grains that extend along the growth direction.
4. The microstructure of lake ice changes with both location in the lake and with depth. Consequently, its mechanical properties vary. However, below a certain depth lake ice exhibits a very tight S1 orientation.

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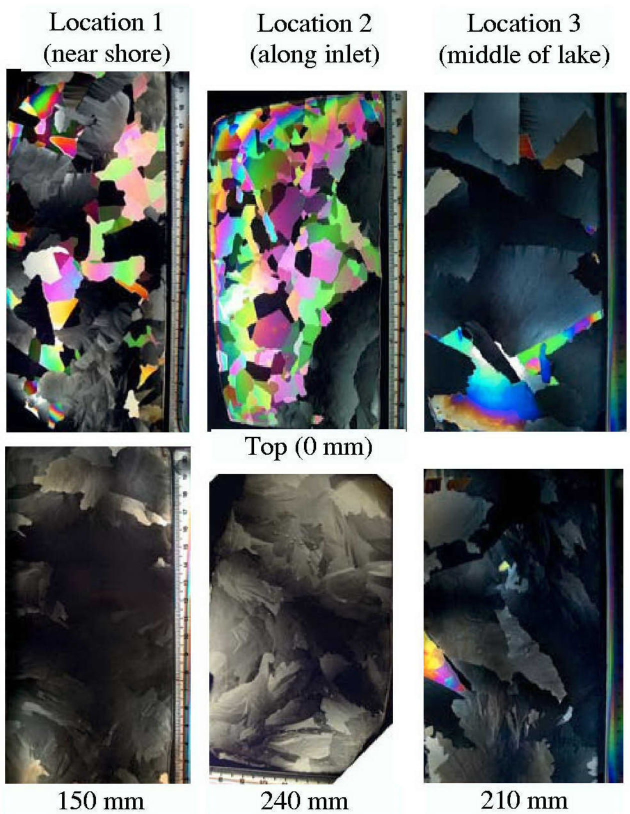

Fig. 1: Thin-sections of lake ice from two different depths and from three different locations. Below a certain depth, which depends on location, the lake ice exhibits an essentially S1 orientation.

3.2 River Ice

It was found that the presence of a constant current leads to an ice cover that is thinner than that of an undisturbed lake in similar regional meteorological conditions. Thin sections from the accretion river ice revealed that both the texture and microstructure of the river ice are significantly different from lake ice (Fig. 2). In particular, the following differences were noted:

1. Overall, accretion river ice was more finely grained than lake ice (qualitatively, compare Top microstructures in Fig. 1 and 2).
2. The majority of the grains had non-S1 orientations.
3. Although larger grains of S1 orientation developed towards the bottom of the ice sheet, the microstructure of river ice we investigated never became exclusively S1.

3.3 Mechanical Behavior Of Lake And River Ice

The strength of lake ice is very variable. At one extreme is the ice that has been exposed to relatively few disturbances during its nucleation process. Such ice, mostly the top layers of the ice cover in middle of the lake (Location 3) or away from shores and possible currents, is in general characterized by longer and relatively straighter grain boundaries (see Top of Location 3 ice in Fig. 2). Such grain boundaries are weak interfaces that will readily crack and side under relatively low applied loads causing the specimens to fail prematurely (Fig. 3). At the other extreme is the deeper and rather exclusively S1-oriented ice, which has been shown to be 1.5-1.7 time stronger than laboratory grown S2 ice (16-17 MPa compared to 10-11 MPa under similar loading conditions).

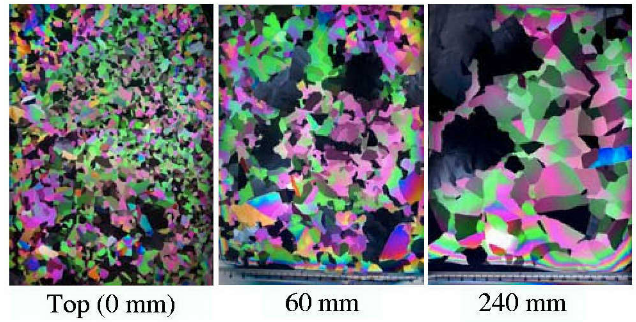

Fig. 2: Thin-sections along the thickness of river ice.

Fig. 3: Compression test specimen made from lake ice from Location 3(middle of lake). *Left: untested. Long and straight grain boundaries are visible in polarized light. Right: tested. Ice failed readily at only 3-4 MPa (compared to 9-10 MPa for lab S2 ice) through cracking and sliding along the inclined grain boundaries.*

The results from the compression tests indicated that, for similar a grain size, the strength of river ice was virtually undistinguishable from that of S2 laboratory ice.

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CONCLUSION

Our results indicate that the mechanical behavior of lake ice cannot be predicted based on data from laboratory grown ice.

Moreover, the mechanical behavior of river ice is different than that of lake ice.